POWER SUPPLY DESIGN USING THE ICL 8211 AND 8212

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INTRODUCTION

The Intersil ICL 8211/12 are micropower bipolar monolithic integrated circuits intended primarily for precise voltage detection and generation. These circuits consist of an accurate voltage reference, a comparator and a pair of output buffer/drivers.

Specifically, the ICL 8211 provides a 7mA current limited output sink when the voltage applied to the THRESHOLD input is less than 1.15 volts. Figure 1 shows a simplified block diagram of the ICL 8211.

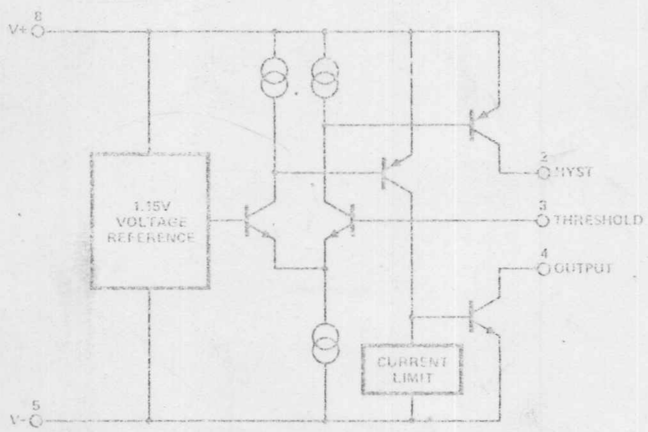

Figure 1:
ICL 8211 Block Diagram

The ICL 8212 provides a saturated transistor output (no current limit) whenever the input THRESHOLD voltage exceeds 1.15 volts. Both circuits have a low current HYSTERESIS output which is turned on when the THRESHOLD voltage exceeds 1.15 volts, enabling the user to add controlled hysteresis to his design. Figure 2 shows a simplified block diagram of the ICL 8212.

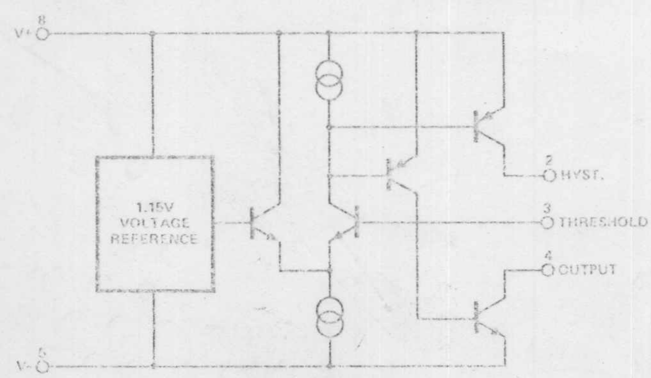

Figure 2:
ICL 8212 Block Diagram

For a detailed circuit description of the ICL 8211/ 12 refer to the data sheet pages 4 and 5. For large volume applications the ICL 8211/12 may be customized by the use of metal mask options to include setting resistors or to vary the output options, or even to adapt the circuit as a temperature sensing element.

Applications for the ICL 8211/12 include a variety of voltage detection circuits, power supply malfunction detectors, regulators, programmable zeners, and constant current sources. In this discussion we will explore the uses of the ICL 8211/12 in power supply circuits of various types. Their attractiveness to the power supply designer lies largely in their ability to operate at low voltage and current levels where standard power supply regulator devices cannot be used. In addition, the unique features of the ICL 8211/12 make them useful in many ancillary circuits such as current sources, overvoltage crowbars, programmable zeners and power failure protection.

POSITIVE VOLTAGE REGULATORS

Using the ICL 8211/12 it is possible to design a series of power supply regulators having low minimum input voltage and small input/output differential. These are particularly useful for local regulation in electronic systems as their small input/ output differential results in low power loss.

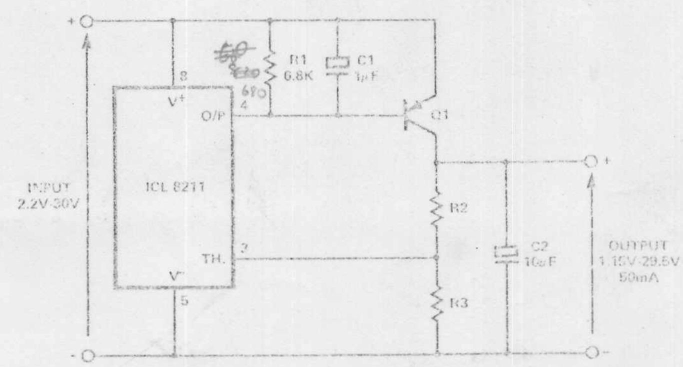

Figure 3:
Positive Regulator — PNP Boost

The ICL 8211 in Figure 3 provides the voltage reference and regulator amplifier while Q1 is the series pass transistor. R1 defines the output current of the ICL 8211 while C1 and C2 provide loop stability and also act to suppress feedthrough of input transients to the output supply. R2 and R3 determine the output voltage as follows:

$$V_{OUT} = 1.15 \times \frac{R2+R3}{R3}$$

In addition, the values of R2 and R3 are chosen to provide a small amount of standing current in Q1, which gives ad-

ditional stability margin to the circuit. Where accurate setting of the output voltage is required, either R2 or R3 can be made adjustable. If R2 is made adjustable the output voltage will vary linearly with shaft angle; however, if the potentiometer wiper were to open circuit, the output voltage would rise. In general, therefore, it is better to make R3 adjustable as this gives failsafe operation.

The choice of Q1 depends upon the output requirements. The ICL 8211 has a worst case maximum output current of 4mA, so with any reasonable device for Q1 the circuit should be capable of 50mA output current with an input to output drop of 0.5V. If larger output currents are required Q1 could be made into a complementary quasi-darlington, but the input/output differential will then increase.

Note also that Q1 provides an inversion within the loop so the non-inverting ICL 8211 must be used to give overall negative feedback.

One limitation of the above circuit is that input voltages must be restricted to 30 volts due to the voltage rating of the ICL 8211. The circuit of Figure 4 avoids this problem.

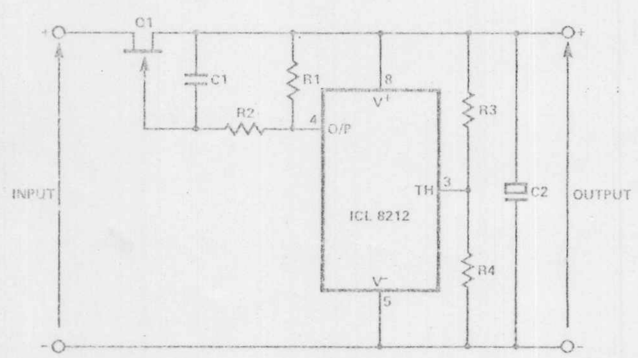

Figure 4:
Positive Regulator – J-FET Boost

In this circuit the input voltage is limited only by the voltage rating of Q1. The input/output differential is now dependent on the $R_{DS(ON)}$ of the J-FET boost transistor. For instance, if Q1 were a 2N4391 the maximum output current would be equal to $I_{DSS(MIN)}$ which is 50mA and the input/output differential would be:

$$R_{DS(ON)} \times I_{LOAD} = 30\Omega \times 50mA = 1.5 \text{ Volts}$$

However, at lower load currents the input/output differential will be proportionately lower.

A further consideration when choosing the FET boost transistor is that its pinch-off voltage must be less than the output voltage in order for the ICL 8212 to be able to pull the gate down far enough to turn the device off at no load.

The predominant loop time constant is provided by R2 and C1. This time constant should be chosen as small as possible commensurate with loop stability as it also affects load transient response. After an abrupt change in load current C1 must be charged to a new voltage level by R2 to regulate the current in Q1 to the new load level and therefore the smaller the R2 x C1 product the better the load transient response. The value of C2 should be chosen to maintain the output within desired limits during the recovery period of the main loop. Note, however, that because of the wide bandwidth of the ICL 8212 and the absence of charge storage effects in the FET, these considerations are not particularly restrictive.

For higher current outputs the system could be further boosted using a bipolar transistor. One attraction of using a FET only output, however, is that the I_{DSS} of the FET gives a measure of output short circuit protection. Should both the low input/output differential of the circuit of Figure 3 plus the extended input voltage capability of Figure 4 be required, the circuit of Figure 5 may be used.

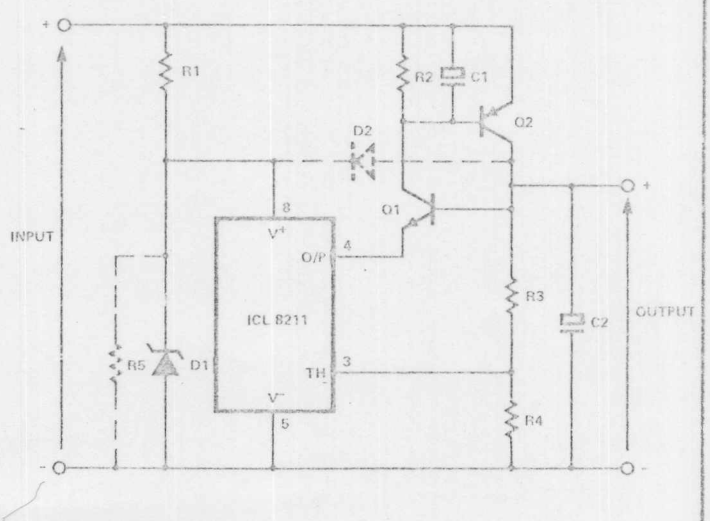

Figure 5:
Positive Regulator – NPN + PNP Boost

This circuit is similar to that of Figure 3 except that Q1 has been added as a common base stage to buffer the output of the ICL 8211 from the input supply and R1 and D1 to protect the input. Unfortunately, the ICL 8211 cannot be supplied from the regulated output as this would result in the power supply being non self-starting. The choice of values for R2, R3, R4, C1 and C2 is identical to that of Figure 3, while D1 must be a voltage equal to or larger than the output voltage. R1 must be chosen to provide the relatively low supply current requirement of the ICL 8211. An alternative arrangement for starting the circuit is to replace D1 with R5 and add D2. In this case the choice of R1 and R5 is such that once the output supply is established the ICL 8211 is supplied through D2.

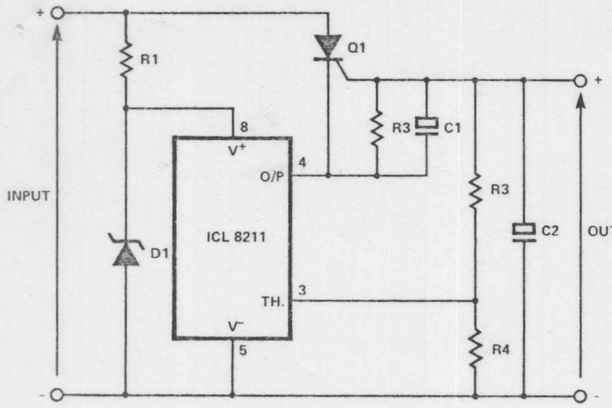

Figure 6:
Positive Regulator – Thyristor Boost

In the circuit of Figure 5, Q1 and Q2 are connected in the classic S.C.R. or Thyristor configuration. Where higher input voltages or minimum component count are required the circuit of Figure 6 can be used. The thyristor is running in a linear mode with its cathode as the control terminal and its gate as the output terminal. This is known as the remote base configuration.

A word of warning, however. Thyristor data sheets do not generally specify individually the gain of the PNP portion of the thyristor, on which the circuit relies. It must therefore either be very conservatively designed or some screening or guarantee of the PNP gain be provided.

Note that, with the exception of the I_{DSS} limit of Figure 4, none of the circuits so far described provide output current limiting. In general they are intended for applications in which the extra voltage drop of a current sensing resistor would be unacceptable. Where the circuits are used as local regulators and the output supplies are only connected to local circuitry the chance of output short circuits is relatively low and overcurrent protection is considered unnecessary. Where protection is required it can be added by any of the standard techniques. Figure 7 shows the simplest possible constant current protection added to the circuit of Figure 3

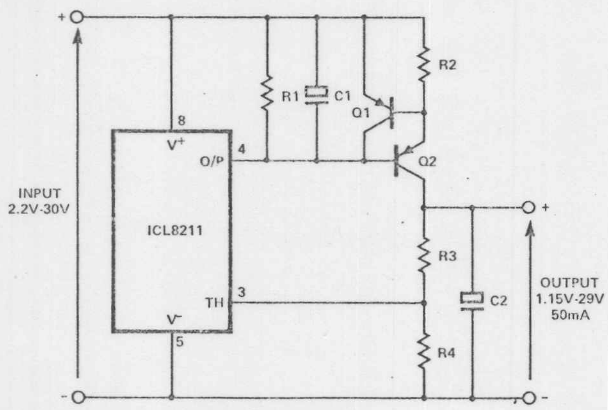

Figure 7:
Positive Regulator – PNP Boost
Current Limited

In this circuit the current threshold is set by the base-emitter voltage of Q1 so that when the voltage drop in R2, due to load current, is sufficient to turn on Q1 base drive is removed from Q2 by Q1 collector. Note that this circuit works only because the output current of the ICL 8211 is current limited so that there is no danger of Q1 and the ICL 8211 blowing each other up with unlimited current.

NEGATIVE VOLTAGE REGULATORS

Because the reference voltage of the ICL 8211/12 is connected to the negative supply rail, and their output consists of the open collector of an NPN transistor, it is not possible to construct a negative equivalent of the circuit of Figure 3. However, a negative equivalent of Figure 4 is easily constructed.

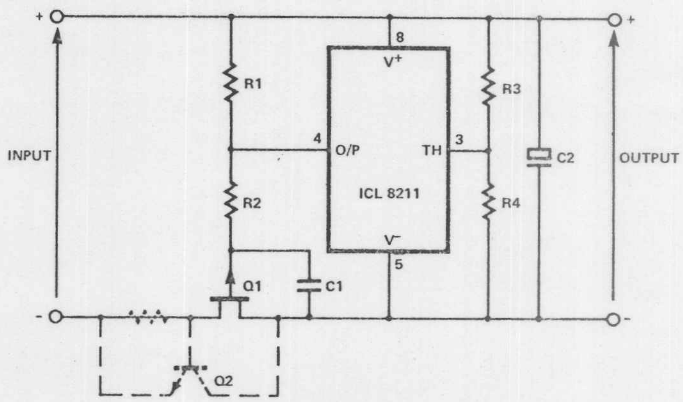

Figure 8:
Negative Regulator – J-FET Boost

Of course the J-FET must now be a P-channel device but otherwise the design considerations are identical to those for Figure 4. Should further boost of the output current level be required, an NPN boost transistor, Q2, (shown dotted) can be added. However, the charge storage effects of the NPN transistor will reduce the loop bandwidth so that R2 or C1 should be increased to maintain stability. Note also that in the circuit of Figure 8 an ICL 8211 is used instead of an ICL 8212 in order to maintain correct feedback polarity.

This is the closest negative equivalent to the circuits of Figures 5 and 6. In this case R1, R2 and D1 ensure that the circuit is self starting. The divider R1/R2 must be chosen to ensure that sufficient voltage (say −1 volt) is present at the base of Q1 to start the circuit under minimum output voltage conditions, but once the circuit is running D1 must remain forward biased even at maximum input voltage, otherwise the output of the ICL 8212 will be unable to pull the emitter of Q1 low enough to turn it off under no load conditions. Thus for a 3 volt output supply which runs from a minimum 4 volt input the ratio of R1 to (R1 + R2) must be one quarter. In order that the base of Q1 is not taken below −3V once the circuit is running the maximum input voltage would therefore be −12V. An alternative arrangement which avoids this restriction is to replace R1 with a zener diode, reduce the value of R2 and delete D1.

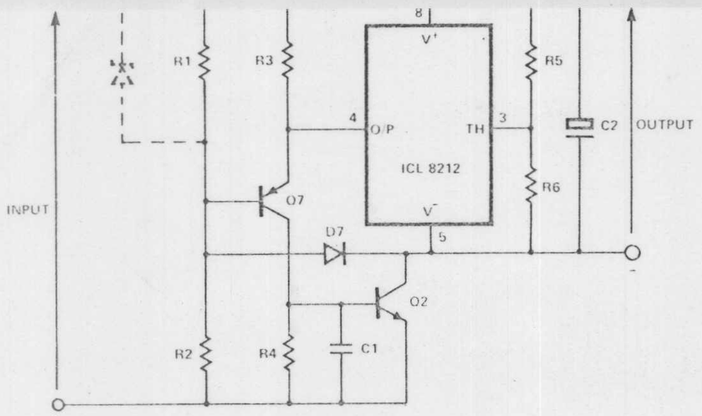

Figure 9:
Negative Regulator – NPN + PNP Boost

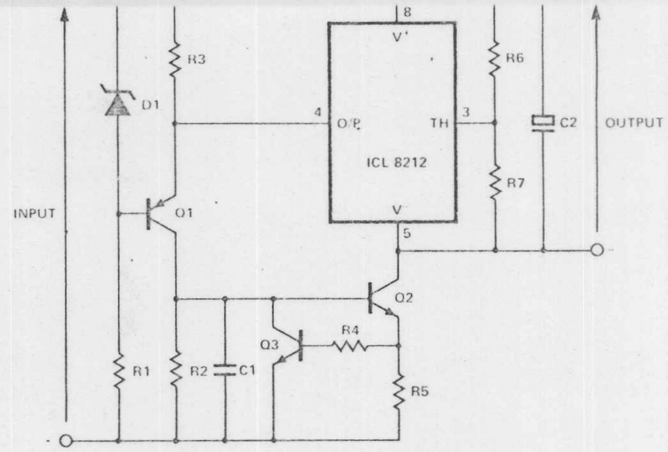

Figure 10:
Current Limited Negative Regulator
– NPN + PNP Boost

In this case the only restriction is that the zener voltage shall be less than or equal to the output voltage of the regulator.

In the circuit of Figure 9, R3 must be chosen to provide sufficient base drive for Q2 via Q1 under maximum load conditions. The maximum value of the current in R3 which may be tolerated is 12mA, the worst case sink current of the ICL 8212 output transistor.

Current limit can be applied to the circuits of Figure 9 in an analogous manner to Figure 7. In this case R3 is the current source for the base of Q2, ensuring that the current limit transistor Q3 has a defined maximum collector current.

ANCILLARY POWER SUPPLY CIRCUITS

Figure 11 shows the ICL 8212 connected as a programmable zener diode. Zener voltages from 2 volts up to 30 volts may be programmed by suitable selection of R2, the zener voltage being:

$$V_Z = 1.15 \times \frac{R_1 + R_2}{R_1}$$

Because of the absence of internal compensation in the ICL 8212, C1 is necessary to ensure stability. Two points worthy of note are the extremely low knee current (less than 300μA) and the low dynamic impedance (typically 4 to 7 ohms) over the operating current range of 300μA to 12mA.

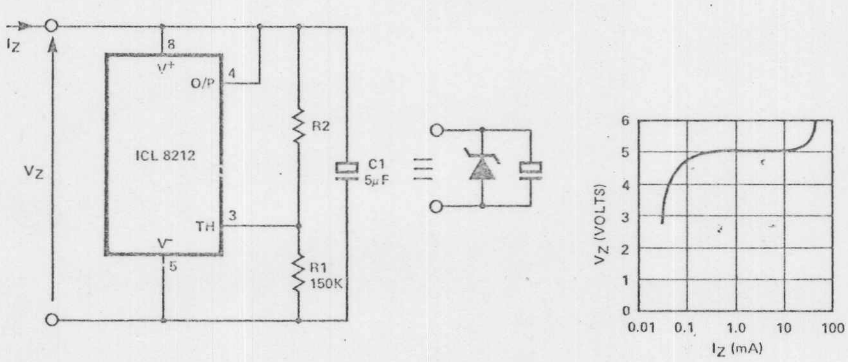

Figure 11:
Programmable Zener

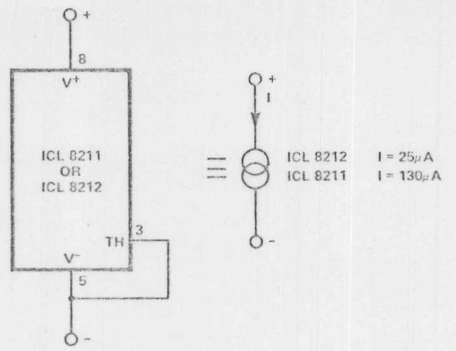

Figure 12:
Constant Current Sources

The circuit of Figure 12 shows how the ICL 8211/12 may be used as constant current circuits. At the current levels obtained with the ICL 8211 or 12 on their own, the principal application will be in providing the "tail" currents of differential amplifiers which may be used in power supply design. A more useful application in power supplies is the programmable current source shown in Figure 13.

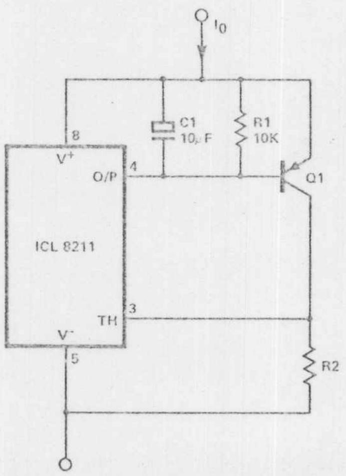

Figure 13:
Programmable Current Source

In this case the output current is given by:

$$I_O = 25\mu A + \frac{V_{BE}}{R1} + \frac{1.15}{R2} \ (1 + \beta)$$

where β is the forward current gain of Q1 and V_{BE} is its emitter-base voltage. The principal causes of departure from a true current source for this circuit will be the variations in β with collector voltage of Q1. With the current settable anywhere in the range of about 300μA to 50mA and an operating voltage range from 2 to 30V, this circuit is particularly suitable as the current source driving the base of an output transistor in conventional series regulator power supplies. Another useful application is as the current source feeding a reference zener in highly stable reference supplies. Again, because of the absence of internal compensation in the ICL 8212, C1 is provided to ensure loop stability. It also helps to keep output current constant during voltage changes or transients.

The standard method of overcurrent protection in simple series regulated supplies is shown in Figure 14.

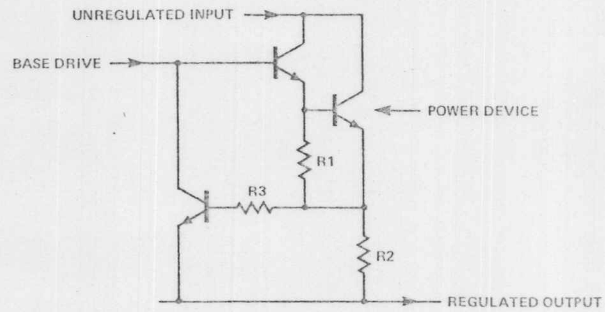

Figure 14:
Standard Current Limit

The current limit value is simply:

$$I_{CL} = \frac{V_{BE}\ (Q3)}{R2}$$

The disadvantages of this circuits are the poor temperature coefficient of the emitter base voltage of Q3, the large variation of V_{BE} between different devices and the badly defined transition between constant voltage and constant current states due to the low gain of the current regulation loop.

In this case the current limit value is:

$$I_{CL} = \frac{1.15V}{R2}$$

One advantage of the circuit is the much improved temperature coefficient of the limit current. In Figure 14 the typical coefficient is 0.3%/°C, while in Figure 15 the typical coefficient is 0.02%/°C. In addition, the higher gain of the ICL 8212 gives a much sharper transition between voltage limit and current limit conditions. The spread of threshold voltages will also be lower in this circuit, but if precise adjustment of the threshold is required R3 and R4 may be added as shown in Figure 15.

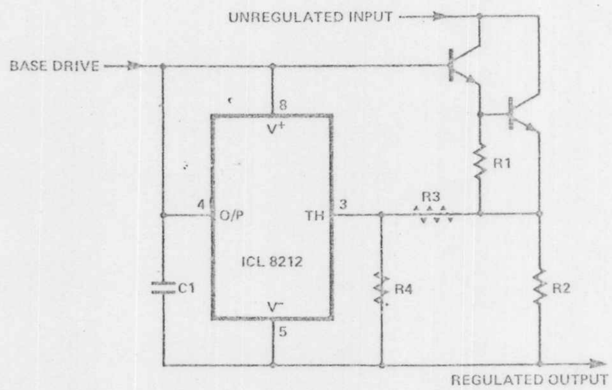

Figure 15:
Improved Current Limit

The major penalty of the system is the extra 500mV which must be dropped in R2 to effect current limiting. Note again that the low operating voltage and power supply current allow the ICL 8212 to be powered directly from the base drive voltage of the power supply.

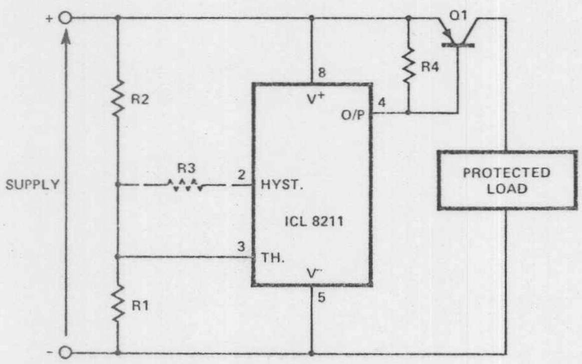

Figure 16:
High Voltage Dump Circuit

This circuit protects sensitive loads against high voltage transients on the power supply rail. Should the input voltage exceed the threshold set by R2 and R1, the ICL 8211 will turn off Q1 and hence protect the load from the transient. R3 provides optional voltage hysteresis if so desired.

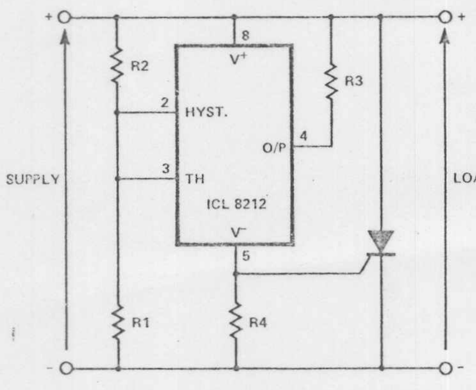

Figure 17:
Overvoltage Crowbar

The most popular form of overvoltage protection is the Thyristor crowbar, which short circuits the supply in the event of an overvoltage condition. The circuit of Figure 17 triggers a thyristor when the supply voltage reaches a threshold defined by R1 and R2. The very low quiescent current of the ICL 8212 means that there is negligible voltage drop in R4 during sensing so that accuracy is unimpaired and there is no danger of triggering the thyristor. The connection from pin 2 provides hysteresis which is necessary in this case because the reference will rise on the top of R4 as soon as the threshold is reached and otherwise would provide negative feedback, which is overcome by the large positive feedback from pin 2. Resistor R3 limits the output current of the ICL 8212 to a safe value of, say, 20mA. To operate properly the thyristor should have a gate trigger current not greater than about 10mA. Where higher gate currents are necessary the circuit of Figure 18 may be used.

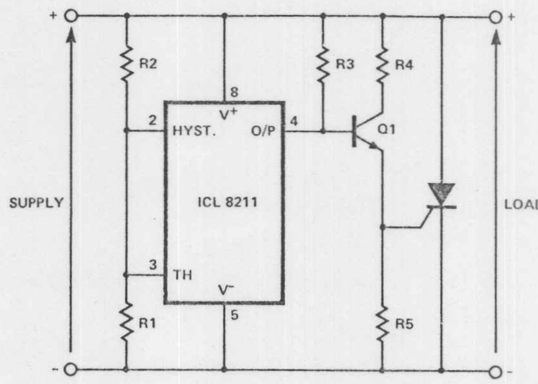

Figure 18:
Overvoltage Crowbar

In this case the ICL 8211 holds down the base of Q1 until the circuit is triggered. The current in R3 should not exceed 4mA as this is the worst case current the ICL 8211 can sink at its output. With this circuit thyristors requiring gate drives in the 50 to 100mA region are easily tolerated.

Notice that in both the above circuits no extra supplies are needed to make the crowbars work down to voltages as low as 3V. In particular, this makes the circuits most suitable for use on 5V logic supplies where no other rails may be available to power a crowbar circuit or where, for reasons of safety, one does not wish to rely on auxiliary supplies.

In some systems it is undesirable to allow the supply rail to be partially established. For instance, in a logic system logical malfunctions may occur. Another example is the LM199/299/399 temperature stabilized reference. If the heater supply falls below about 9V the unit tends to "run away" and destroy itself.

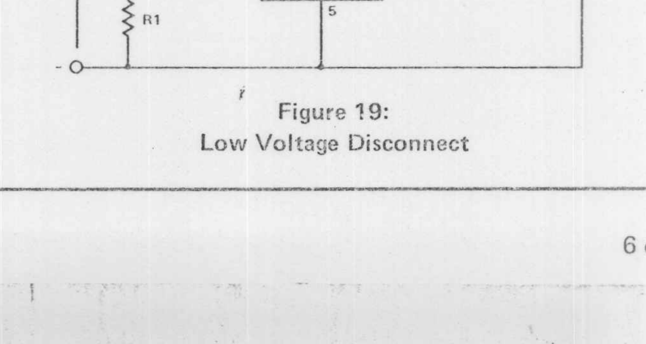

Figure 19:
Low Voltage Disconnect

Should the power supply voltage fail below the level determined by R1 and R2, Q1 is turned off, disconnecting the load entirely so that it cannot operate at partial voltage. Note that the removal of the load may cause the supply voltage to rise and the possibility of an oscillatory condition exists. Resistor R3 therefore provides a small hysteresis, which should be calculated to exceed the full load regulation drop of the supply.

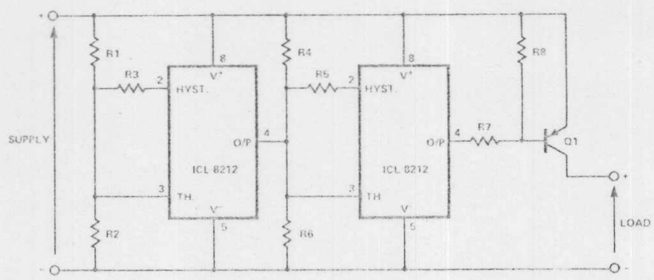

Figure 20:
Power Supply Window Detector

The circuits of Figures 16 and 19 can be combined so that a load is only connected to the supply when the supply voltage is within a specified range. In this case IC1 senses the overvoltage condition while IC2 senses the undervoltage condition. Again, hysteresis may be added as necessary by the addition of R3 and R5.

In many systems, particularly those using microprocessors, it is necessary to provide a logic signal which gives advance warning of an impeding power failure so that the system can execute a shutdown routine before power is lost. A simple undervoltage detector on the regulated supply is generally insufficient as by the time an undervoltage signal is generated, the supply is already out of regulation and unless it falls very slowly there will not be sufficient time to shut the system down properly.

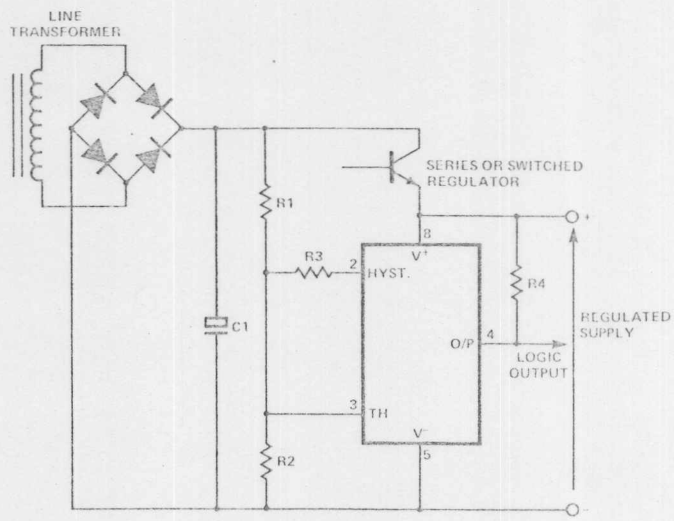

Figure 21:
Simple Power Fail System

In the circuit of Figure 21, an incipient power failure is detected at the unregulated input of the regulator. Note that the value of main reservoir capacitor C1 must be large enough so that the shutdown routine can take place before the regulator drops out of regulation. Waveforms for a typical power failure are shown in Figure 22.

The threshold detector should be an ICL 8212 if a logic '1' is required to initiate shutdown, or an ICL 8211 if a logic '0' is required. Note that the ICL 8212 will drive 7 T.T.L. loads and the ICL 8211 2 T.T.L. loads.

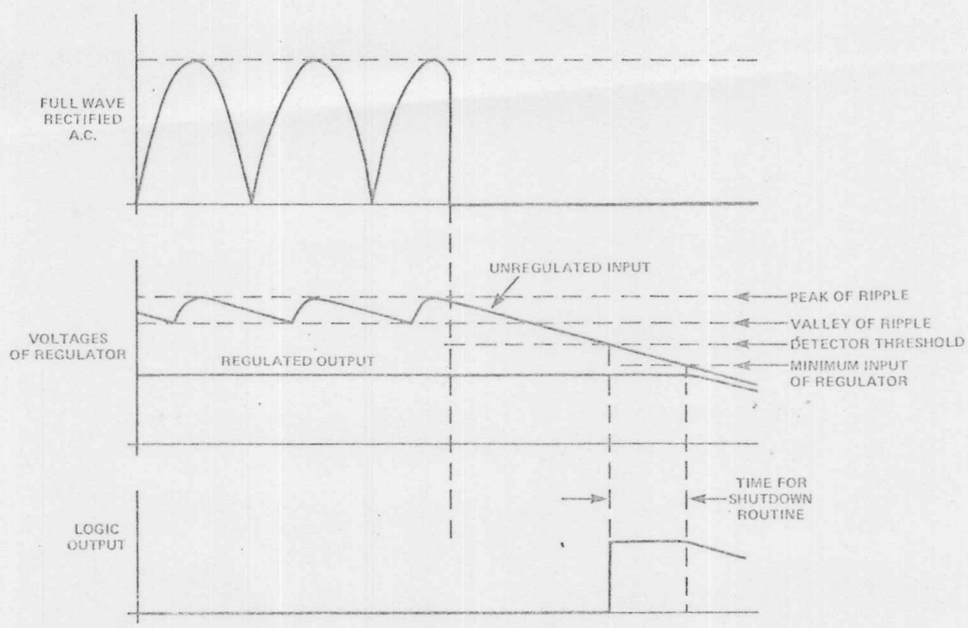

Figure 22:
Simple Power Fail System Waveforms

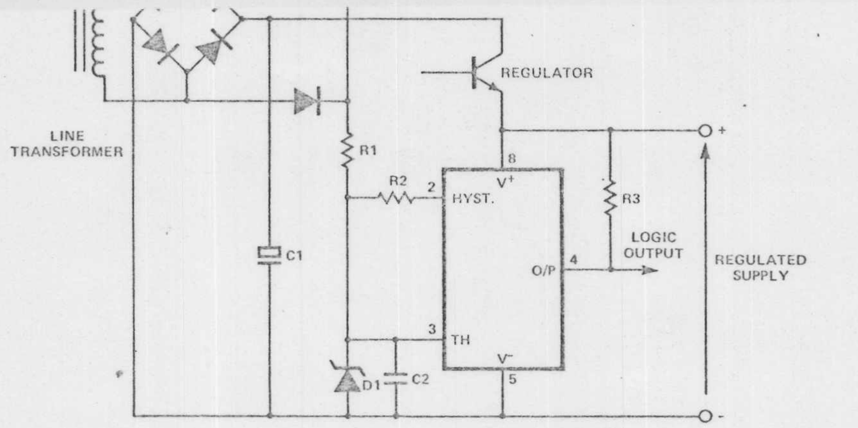

Figure 23:
Improved Power Fail System

Notice that, because of the ripple always present on the unregulated supply, power failure was not actually detected until some time after the removal of input power. This waste time means that larger voltage margins must be built into the system, reducing the regulator efficiency under normal operating conditions. In some instances, however, this circuit may be adequate.

In Figure 24, the power is monitored at a point isolated from the main capacitor C1 so that failure can be detected without having to wait for C1 to discharge below the minimum voltage of the normal ripple. Waveforms for this circuit are shown in Figure 24.

In this case R1 tops up C2 to the zener voltage each cycle, while C2 holds the input of the ICL 8211 or ICL 8212 (depending on the polarity of the required output signal) above its threshold during the zero crossings of the A.C. waveform. However, in the event of a power failure, C2 discharges through R2 to the threshold voltage of 1.15 volts, at which point the power fail signal is activated.

In this case, the worst point at which a power failure can occur is just before C1 begins to charge on the rising side of the input A.C. signal. However, because of the fast warning given by the system, it is still superior than that of Figure 21 in the time allowed for a shutdown routine.

CONCLUSIONS

Just a few of the many possible applications of the ICL 8211 and ICL 8212 in power supply systems have been described. Both in power supply systems and elsewhere, the features of the ICL 8211 and ICL 8212 make them very useful general purpose circuits. Once aware of the useful features of these low power, low voltage circuits the designer will rapidly discover a large number of applications for himself.

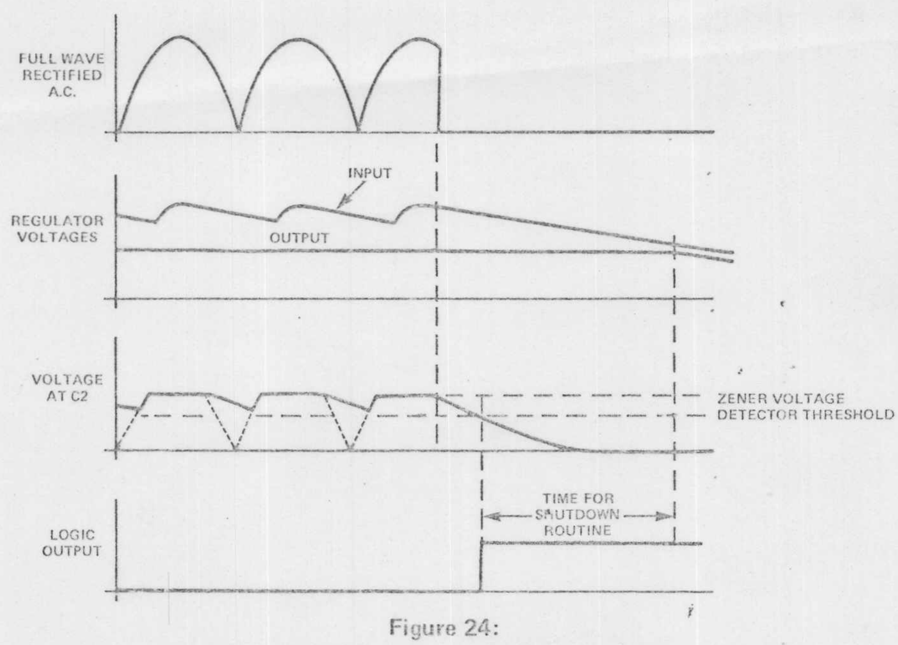

Figure 24:
Improved Power Fail System Waveforms